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THERMOSTAT LOCATION FOR A NATURALLY VENTILATED SWINE BARN

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SUMMARY: The recommended location of thermostats in an Automatically Controlled Natural Ventilation barn was determined based on the ability to establish comfort zones for the animals and to minimize the effect of wind direction and exterior temperature.

Thermostats located at 0.9 m above the floor, 3.3 m from the outside walls, at midlength of the barn provided adequate environmental control under all conditions studied.

KEYWORDS: Thermostat, location, natural ventilation.

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INTRODUCTION

The location of the thermostat can affect the performance of natural as well as mechanical ventilation systems. Many recommendations have been made regarding locations for thermostats for mechanical ventilation systems but very few recommendations exist for natural ventilation systems.

According to the Ontario Ministry of Agriculture and Food ventilation manual (Huffman, 1984), the recommended thermostat location should be as close as practical to the livestock living space, but not near a warm ceiling, or a cold wall, and not exposed to sunlight. "They should be in the normal air flow of the barn, near the animals and in an area where they can be easily read, adjusted and kept clean".

The purposes of a thermostatic control system are to :
1- provide a comfort zone over the sleeping area and
2- minimize temperature fluctuations in the animal space regardless of the variability of outside temperature and wind.

During the falls of 1986 and 87, data were collected to establish the preferred thermostat locations along and across an Automatically Controlled Natural Ventilation (ACNV) building for growing-finishing hogs.

LITERATURE REVIEW

Thermostat location for automatically controlled natural ventilation.

Bird (1984) recommended that thermostats be located half-way along the barn, close to the sets of ventilation doors they control and 1.5m above the floor.

Anon (1984), Spackman et al. (1983), and Strom and Morsing (1984) reported the capability of an ACNV system to maintain indoor temperature between 15 and 20°C in cold weather. Barns studied had thermostats centrally located in the room (centre alley layout) between 1.5 and 1.8 m above the floor.

In Ontario, MacDonald et al. (1985) found 7-10°C temperature gradients across and along an ACNV barn at an outside temperature of -10°C. Here only one thermostat, located in the middle of the room was used to control the sidewall openings. Similar temperature fluctuations were observed by Borg and Huminicki (1986) for the cold weather conditions of the Canadian Prairies.

Barrie (1986) studied an ACNV finishing barn where the thermostats were centrally located in the room at 2.6 m above the floor. He recommended adjusting the thermostats to 17°C in order to obtain a target temperature of 14°C at floor level. He also

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noted vertical and horizontal temperature gradients in the barn which varied with wind speed and direction.

Owen (1984) described a controller which could accommodate several temperature sensors. It was anticipated that this controller would reduce temperature gradients in the barn since its action was based on the average temperature of several locations. It should also be less affected by other features such as empty pens. He also discussed the importance of a time delay between temperature readings by the controller in order to prevent frequent door adjustments.

During the winter of 1984-85 Choinière (1985) evaluated a non-modulated natural ventilation system where the thermostats were 2.1m above the floor at the mid-length of the barn. Large temperature fluctuations were noted at floor level while the temperatures at 2.1m were quite stable. Based on observations of the air flow patterns and temperature profiles, he recommended that thermostats be located on both sides of the barn, 3.3meters from the wall and that they should be located 0.9m above the floor for outside temperatures below $0^{o}C$ and 1.5m for outside air temperature above $0^{o}C$. These were locations exhibiting large temperature fluctuations. Thermostats were located midway along the building.

For natural ventilation, no other literature was found giving thermostat location recommendations based on observations of temperature profiles and fluctuations, or air flow patterns.

Identification of variables

Several variables affect temperature control inside a naturally ventilated building. Hellickson et al. (1983), Bird (1984) and Milne (1984) classified some variables such as wind direction and speed and exterior temperature as being uncontrollable. The type of building, its orientation, interior layout, type of air inlets and outlets, and related animal management factors are controllable variables; these should be chosen to give the best possible environmental conditions in the barn in relation to the uncontrollable variables.

Uncontrollable variables

Barrie (1986) stated that the weather conditions have direct effects on the temperature zones along and accross the barn. For isothermal conditions, Ogilvie and Boyd (1985) stated that the wind direction is the dominant influence on the three dimensional airflow patterns. Strom (1987), Mitchell and Ross (1977), and Choinière et al. (1986) studied isothermal two dimensional air flow patterns for a cross section of a gable roofed naturally ventilated barn. In another study Choinière et al. (1986) reported the differences in airflow patterns between isothermal and non-isothermal conditions.

Prediction of air flow patterns and temperature zones

Randall (1975) described many airflow patterns in relation to the difference in temperature of the incoming air stream and the ventilated airspace using Archimedes numbers.

Leonard and McQuitty (1986) observed the penetration of air jets into a ventilated air space and used Archimedes numbers to predict the stability of the airstreams. DeBruyckere and Neuckermans (1968) discussed the relation of temperature profiles to airflow velocities, and patterns and stated that such information was essential for the development of a control strategy for barn ventilation.

Comfort zone for finishing pigs

According to Curtis (1983), an animal can survive and grow in a variety of temperature zones. The optimal temperature range for animal growth is called the thermal comfort zone. This zone is somewhat above the lower critical temperature (LCT), but below the upper critical temperature (UCT). Choinière et al. (1986) discussed these aspects and considered the "optimal" zone for 40 kg finishing hogs to be between 17 and 19^{o}C, the "cool" zone to be between 15 and 17^{o}C, and the "cold" or "discomfort" zone to be below 15^{o}C. These considerations were based on work by De La Farge (1981), and Yousef (1983).

Curtis (1983) also stated the importance of ventilation patterns and temperature control in relation to animal activities such as eating, drinking, dunging and sleeping. Choinière et al. (1986) emphasized the fact that: "A natural ventilation system should be able to establish a comfort zone where pigs could sleep without excessive temperature fluctuations".

OBJECTIVES

The purpose of this study was to determine a preferred thermostat location in an ACNV growing-finishing hog barn in order to provide a comfort zone over the sleeping area, and to determine the effects of wind direction and the outside temperature on this location.

The performance of the temperature control system was evaluated by assessing temperature profiles and fluctuations. Air flow patterns were used to indicate air velocity distributions.

TEST PROCEDURES AND INSTRUMENTATION

The monitored barn was a 10.8 x 23.0 m naturally ventilated, growing-finishing barn (Fig. 1) owned by A. de Wit of Spencerville, Ontario.

The barn had a centre alley between two rows of 2.4 x 4.8 m pens. The pens had solid wall partitions and solid pen fronts.

This barn length was oriented north-south and attached at the north end to a mechanically ventilated barn with matching roof and wall planes. A continuous ridge outlet was manually adjustable. The barn was equipped with an automatic modulated control system consisting of two thermostats, time delays, and gear motor driven actuators that opened or closed the rotating ventilation doors in the side walls.

The adjustable timer activated the control system, in this case the thermostats, periodically (for example, every three minutes), which in turn activated a gear motor to open or close the ventilation doors. An adjustable time delay controlled the length of time that the gear motor was energized after being activated (for example 3 seconds). This allowed the doors to move in increments of about 20 to 30 mm, thus modulating the operation of the system. The thermostats had a dead band of about 2°C. This modulated system was distributed by Faromor Inc., Waterloo, Ontario.

Location of the thermostat

Following the recommendation of Bird (1984) and Choinière (1985), the thermostats were located midway along the barn and 3.3m from the outside walls. Also recommended was the use of separate thermostats to control the inlet doors on each side of the barn. Two thermostat elevations : 0.9 and 1.5m above the floor were used for different test periods. The thermostats were carefully adjusted to the same temperature. When thermostats were tested at the 0.9m height, they were protected from the hogs by an electric shocker system similar to that used for cattle.

Wind direction

Fig. 2 shows the four quadrants selected to observe the wind direction effects. There was no upwind interference on the south and the west sides of the barn whereas some buildings were located near or upwind to the north and east.

Outside temperatures

Three outside temperature ranges were selected to represent isothermal, intermediate and cold conditions. They were respectively above 18°C, between +5°C and +18°C, and between -5°C and +5°C. There were no comparative data available for colder temperatures.

For this study, the wind speeds and other environmental factors were not interpreted. However, for comparison purposes, test periods were chosen when wind speeds were similar.

Test periods and instrumentation

The building was monitored continuously from October 1986 to January 1987 and from September 1987 to November 1987. Thermostats were installed at 0.9m and 1.5m heights alternatevily on a weekly basis. During the experiment, the continuous ridge outlet had an opening width of 20 mm (0.4m^2 for the whole barn).

As indicated in Fig. 1, 20 thermocouples were used to sense temperatures over the central cross section of the barn. This profile indicates the general thermal behavior of the barn. Along the building, 30 thermocouples (including 8 thermocouples from the central cross section) at 0.9m above the floor, were used to sense the temperatures (Fig. 2). A weather station next to the barn indicated exterior temperature, relative humidity, wind speed and direction. While testing, all readings were taken at intervals of 10 seconds, but averaged over a 10-minute period. The data were transferred from the datalogger to an IBM-PC for further analysis using commercial software (Lotus 1-2-3). A land drainage program, Macdrain, developed by Kok and Tremblay (1986), was used to plot isothermal contours from the data.

Air flow patterns were observed using air current smoke tubes.

RESULTS AND DISCUSSION

Thermostat adjustment

Thermostats on both sides of the barn were adjusted to within ± 0.5°C of each other. As shown in the temperature profiles (Figs. 3 to 7, the temperatures close to the thermostats remained within one degree indicating that quite presise adjustment was achieved.

Previous data had shown that unequal adjustment of the thermostats caused the doors on one side of the barn to open more than on the other; this in turn aggravated temperature gradients and fluctuations.

Effects of wind direction on the preferred location of the thermostat along the building length.

Fig. 3 shows temperature profiles and fluctuations along the building for cold weather conditions.

Ogilvie and Boyd (1985) reported that the wind effect dominates over the stack effect for wind speed over 2.0 m/s and a 10°C inside-outside temperature difference. Fig. 3 demonstrates that the wind direction was a significant factor influencing the temperature profiles along a naturally ventilated building.

Wind from the south west created a high negative pressure zone on the ventilation doors in the south east part of the barn. The ridge outlet was also influenced by wind direction. The south end of the ridge (high negative pressure) was the main outlet. Hellickson et al. (1983) reported that winds perpendicular to the building length exerted a fairly uniform pressure along the windward side of the building. Figs. 4 and 5 show temperature profiles of a cross section at the midlength of the barn. For wind perpendicular to the building length, these profiles would remain uniform along the building but for winds parallel to the building length, the profiles varied along the building.

Orientation of the building

For cold weather, it is recommended that a naturally ventilated building be oriented perpendicular to prevailing winds, if they can be identified for the site. No data are presently available to make recommendations for warmer conditions.

Location of the thermostat along the ACNV Building.

For exterior temperatures of about 0°C, and westerly winds, the location of the thermostat along the building was not critical based on the similarity of the temperature profiles. With southerly winds, the central location of the thermostats was satisfactory even though the temperature fluctuations at the north end were greater compared to those obtained with west winds (Fig. 3). No data are presently available for the combination of colder temperatures and south winds (a rare combination at this site). The use of a multi-temperature sensor system as proposed by Owen (1984) would not solve the problem of the longitudinal temperature gradient due to the wind direction effect, but might help to reduce the temperature fluctuations at the north end.

Multi-zone control systems

A possibility to reduce the temperature gradient along the building might be to use a multi-zone control system. This could separate the barn into two or more sections. For this size and orientation of barn, it would be the south and north ends, with independent thermostat and ventilation door controls. Temperature gradients can be caused by wind pressure variation along the barn. To maintain the same total volume of air crossing the building, the multi zone system would close the doors at the cooler end forcing the doors at the warmer end to open. This unequal door adjustment might help to equalize the rate of air entry along the building, and thus temperature gradients and fluctuations might be reduced.

Maximum length of building per control unit.

Results of this study show that one control unit (one thermostat on each side) was barely sufficient to maintain good temperature control for a naturally ventilated building 23m long. Temperatures colder than 0°C or higher wind speeds might have more adverse effects on temperature profiles and fluctuations.

It is recommended to use a multi-control system for a barn longer than 23m, especially if winds parallel to the length of the building are frequently encountered.

Effects of wind direction

Results (Figs. 4 to 7) show that the wind direction (west versus south) had limited influence on the temperature profiles across the midlength of the barn. For both wind directions and the three outside temperatures studied, the thermostat controller was able to provide a comfort zone over the sleeping area. But generally higher temperature fluctuations occurred with south winds as compared to with west winds. During cold weather, temperature fluctuations over the sleeping area in the order of 2.6°C occurred with south winds compared to 1.4°C with west winds.

No data were obtained for such a comparison during very cold outside temperatures.

Effect of outside temperatures

Isothermal conditions

Isothermal conditions occur during warm weather when outside temperatures approach inside temperature. For these conditions, the thermostat location had no influence on the temperature control but the quality of the ventilation relied on the adequacy of the air inlet and outlet design. The inside temperature was never more than 2°C above the outside temperature for the three isothermal tests. The temperature was fairly uniform across the building. Warmer zones were observed close to the walls and close to the center partitions. These zones have been previously identified as stagnant zones by Choinière et al. (1986).

Intermediate conditions

With cooler outside temperatures, the required ventilation rates decreased, causing the air inlet doors to close. Also, the incoming air jets tended to fall rather than to complete a totally developed isothermal airflow pattern. Barber et al. (1982), Randall (1975) and Timmons et al. (1986) described these phenomena by considering the differences in relative densities and the lack of momentum of the air jets. Close to the main incoming air streams temperature fluctuations were greater at the ceiling than at the floor.

A distance 3 to 4 meters from the outside walls corresponded to where the air jets were falling from the ceiling. The highest temperature fluctuations occured along the outside walls, diminishing toward the centre of the barn. The present locations of the thermostats, at 3.3m from the walls were adequate to control temperatures over the sleeping area.

Cold conditions

For outside temperatures below 0° to 5°C, the airflow patterns indicated that the incoming air fell close to the outside walls. The ridge opening acted as the main outlet. Thermostats as located were able to provide desirable environmental conditions.

Thermostat Elevations

Comparison of Figs. 4 to 7 show that both thermostat elevations, 0.9 and 1.5m, maintain the temperature over the sleeping area above the L.C.T. But, for intermediate and especially cold conditions, temperature fluctuations were generally greater when the thermostat was at the 1.5m height.

The preferred elevation for the thermostat is therefore be 0.9m above the floor. However at this location, it must be protected from physical damage by the hogs.

No data were available for thermostat elevations less than 0.9m. A lower location might provide some benefit in control of temperature fluctuations but could also be subject to misleading readings due to the proximity of the hogs.

CONCLUSION

The longitudinal location of the thermostats should be at the midlength of the building in order to minimize temperature variations caused by winds parallel to the building length. As well, for the weather condition studied, thermostats located 3.3m from the outside walls provided comfort zones over most of the sleeping area. Temperature fluctuations were reduced for a thermostat elevation of 0.9m as compared to 1.5m.

RECOMMENDATIONS

Recommendations that evolve from this study in order to adapt the controllable variables (building design, orientation, management, etc.) to the uncontrollable variables (wind direction, outside temperature). They are:

1- For cold weather, an ACNV building should be oriented perpendicular to the prevailing winds.
2- Buildings longer than 23m could benefit from a multi-zone control system, particularly during periods when the wind is not perpendicular to the length of the building.

FURTHER STUDIES

Some other uncontrollable variables that require study are:

1- the effects of wind direction for colder and warmer outside temperatures.
2- the effects of rapid changes of outside weather conditions on the thermal behaviors of ACNV buildings.

Some controllable variables that require study are:

1- the performance of a multi-zone control system for buildings longer than 23m.
2- the development of a temperature sensing element which pigs would be reluctant to touch or other methods of protecting the thermostats.
3- the effects of upwind interference such as adjacent buildings.

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REFERENCES

Anon, 1984, What is ACNV?, Extension Bulletin, the Scottish Farm Buildings Investigation Unit, Aberdeen, p.p.10.

Barber, E.M., Soknansanj, S., Lampman, W.P. and Ogilvie J.R., 1982, Stability of Airflow Patterns in Ventilated Airspaces, Paper No. 82-4551, American Society of Agricultural Engineers, Saint-Joseph, Michigan.

Barrie, J.A, 1986, Cold-Weather Performance of ACNV, Farm Building Progress, October 1986, p.p. 13-17.

Bird, N.A., 1984, Controlled Environment with Natural Ventilation in Single Storey Gable Roofed Barns, Ontario Ministry of Agriculture and Food Ventilation Manual, Chapter 12.

Borg, R. and Huminicki, D.N., 1986, Natural Ventilation in Cold Climates, Paper No. 86-115, Canadian Society of Agricultural Engineers, Ottawa, Ontario.

Choinière, Y., Natural Ventilation vs Mechanical Ventilation for Swine Housing, May 1985 Project Summaries, Canadian Society of Agricultural Engineers Poster Session, Ontario Region, Albert Thornbrough Building, University of Guelph, Guelph, Ontario.

Choinière, Y., Blais, F., Munroe, J.A., and Leclerc J.M., 1986, Winter Performance of Different Air Inlets in a Naturally Ventilated Swine Barn, Paper No. 86-121, Canadian Society of Agricultural Engineers, Ottawa, Ontario.

Choinière, Y., Blais, F., Munroe, J.A., 1986, Air Flow Patterns in Naturally Ventilated Buildings Using a Wind Tunnel, Paper No. 86-122, Canadian Society of Agricultural Engineers, Ottawa, Ontario.

Curtis, S.E., 1983, Environmental Management in Animal Agriculture, The Iowa State University Press, 410 pages.

DeBruyckere, M., Neuckermans, G., 1968, Ventilation - Some Aerodynamic Aspects, Farm Building Digest, 3[15]:11-14, summer 1968.

De La Farge, A., 1981, Is There any Influence of Indoor Climate in Fattening Pigs? A New Design for Fattening Houses, Commission Internationale de Génie Rural, 22 p.p.

Hellickson, M.A., Hiukle, C.N., Jedele, D.G., 1983, Natural Ventilation, Chapter 5, Ventilation of Agricultural Structures, Publication No. 6 p.p.81-100, American Society of Agricultural Engineers, Saint-Joseph, Michigan.

Huffman, H.E. 1984, Ontario Ministry of Agriculture and Food Ventilation Manual, 1984, Thermostats for Temperature Control, Chapter 4.

Kok, R., Tremblay S., 1986, Macdrain, The Computerized Surveying Mapping Drainage Design System, Ontario, Canada.

Leonard, J.J. and McQuitty, J.B., 1986, Archimedes Number Criteria for the Control of Cold Ventilation Air Jets, 28[2]:117-122, July 1986, Canadian Agricultural Engineering Ottawa, Ontario.

MacDonald, R.D., Houghton, G., and Kains, F.A., 1985, Comparison of a Naturally Ventilated to Mechanically Ventilated Hog Finishing Barn, Paper No. 85-402, Canadian Society of Agricultural Engineers.

Milne, R.G., 1984, Guidelines for Natural Ventilations, Ontario Ministry of Agriculture and Food Ventilation Manual, Chapter 12.

Mitchell, C.D, Ross, P.A., 1977, Model Study of Airflow in Two Calf Houses, Farm Building Progress, January 1977, p.p. 19-22.

Ogilvie, J.R. and Boyd, K.G., 1985, Tracer Gas Analysis of Ventilation Due to Wind in Models of a Modified Open Front Swine Finishing Barn, Paper No. 85-413, Canadian Society of Agricultural Engineers, Ottawa, Ontario.

Owen, J., 1984, Ventilation Systems for Intensive Livestock, Farm Buildings and Engineering, 1[4]:13-17, October 1984.

Randall, J.M., 1975, The Prediction of Airflow Patterns in Livestock Buildings, Journal of Agricultural Engineering Research, 20:199-215.

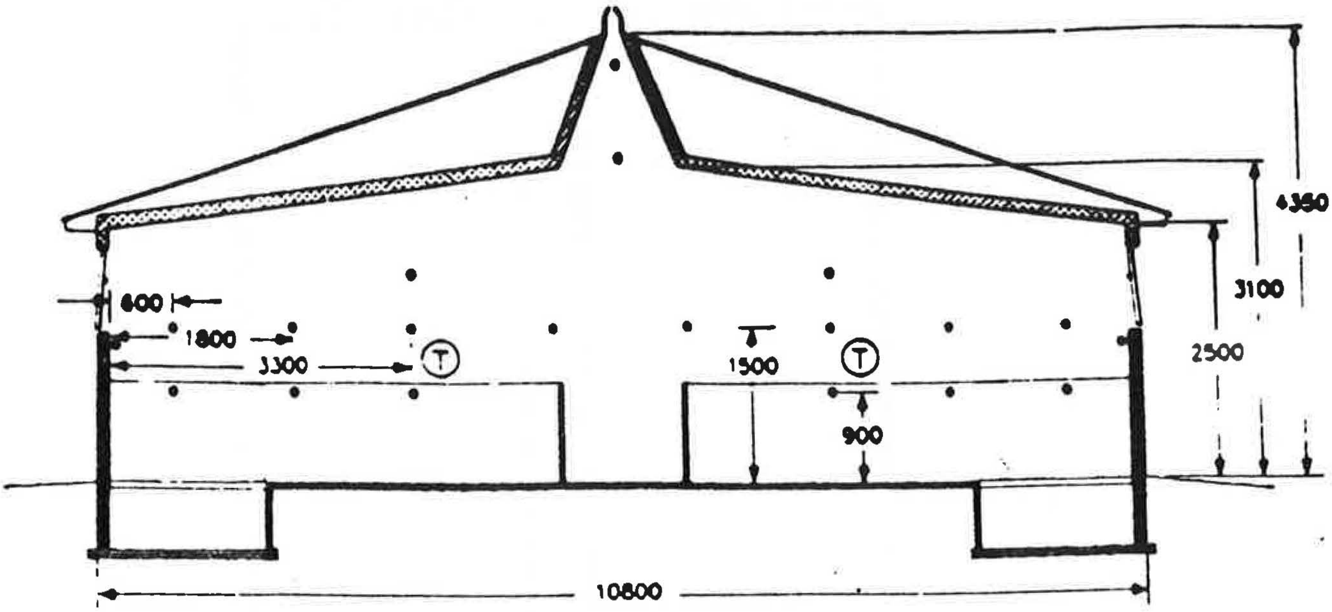
Spackman, E., Armsby, A., Becket, M. and Sheperd, C., 1985, An Analysis of the Environmental Control Achieved in an Automatically Controlled Naturally Ventilated Farrowing House, Paper no. 121, Winter meeting British Society of Animal Production.

Strom, J.S., 1987, Natural Ventilation and Its Control, Pigs, May/June 1987, p.p. 16-17.

Strom, J.S., and Morsing, S., 1984, Automatically Controlled Ventilation in a Growing/Finishing Pig House, Journal of Agricultural Engineering Research, 30:353-359.

Timmons, M.B., Ivish, W.W., and Toleman, W.J., 1986, Temperature Variations Within Caged-Layer Housing as Affected by Inlet Flow Characteristics, transaction of American Society of Agricultural Engineers, 2(2):153-157, November 1986.

Yousef, F.M.K., 1983, Stress Physiology in Livestock - Vol.II: Ungulates. CRC-Press, Boca Raton, Florida.



Length of the building .... 23 000 mm
No. of off center pivot rotating doors 17
Overall insulation .... 3.6 RSI
Scissor truss construction
Orientation .... North-South
Date of construction 1982
• Temperature sensors (T-type thermocouples)
Ⓣ Thermostat, 0.9 or 1.5 m above floor
All dimensions are in millimetres

Figure 1: Central Cross Section of Barn Showing Location of thermocouples

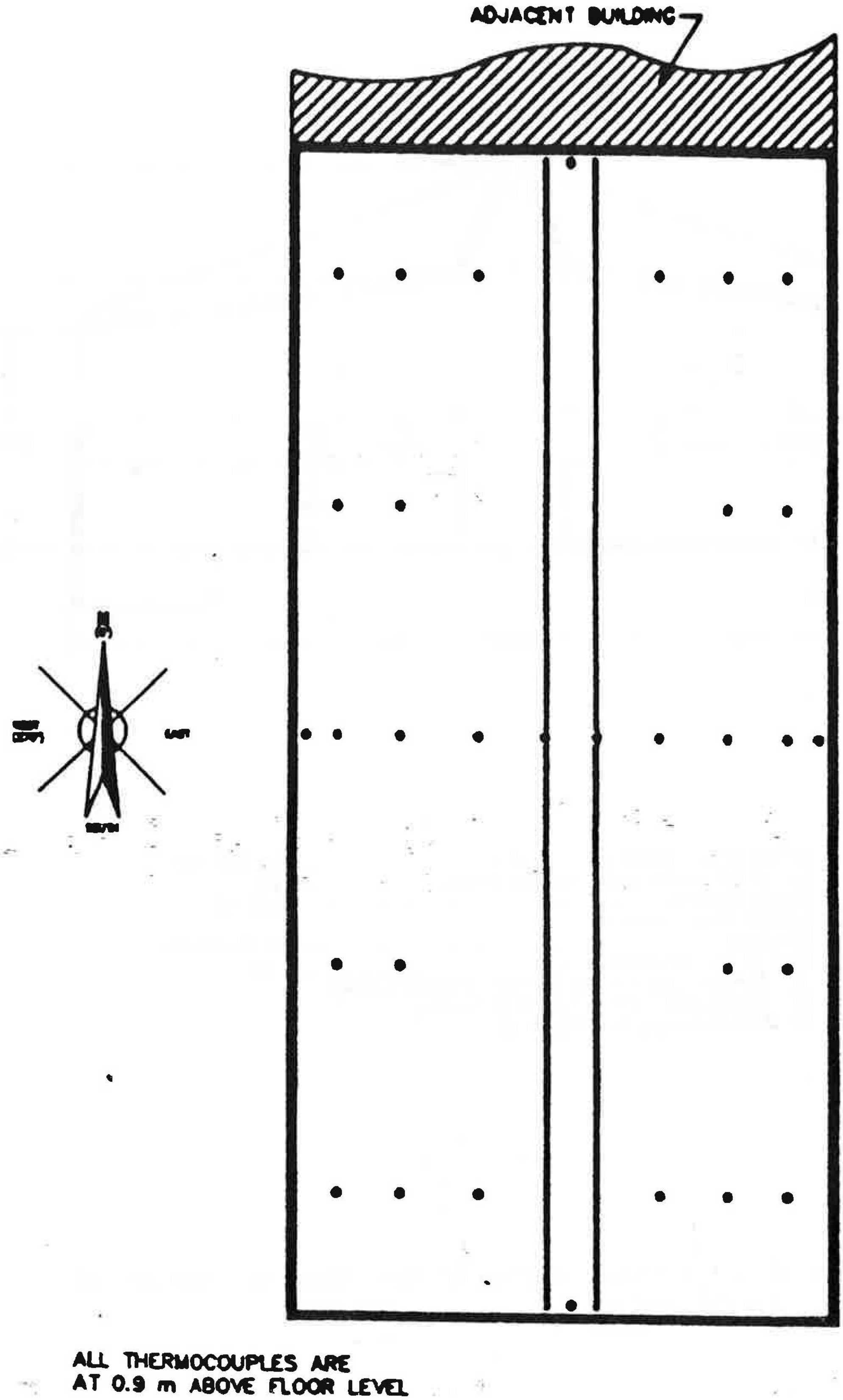


Figure 2: Plan View of Barn Showing Location of thermocouples and orientation of the building.

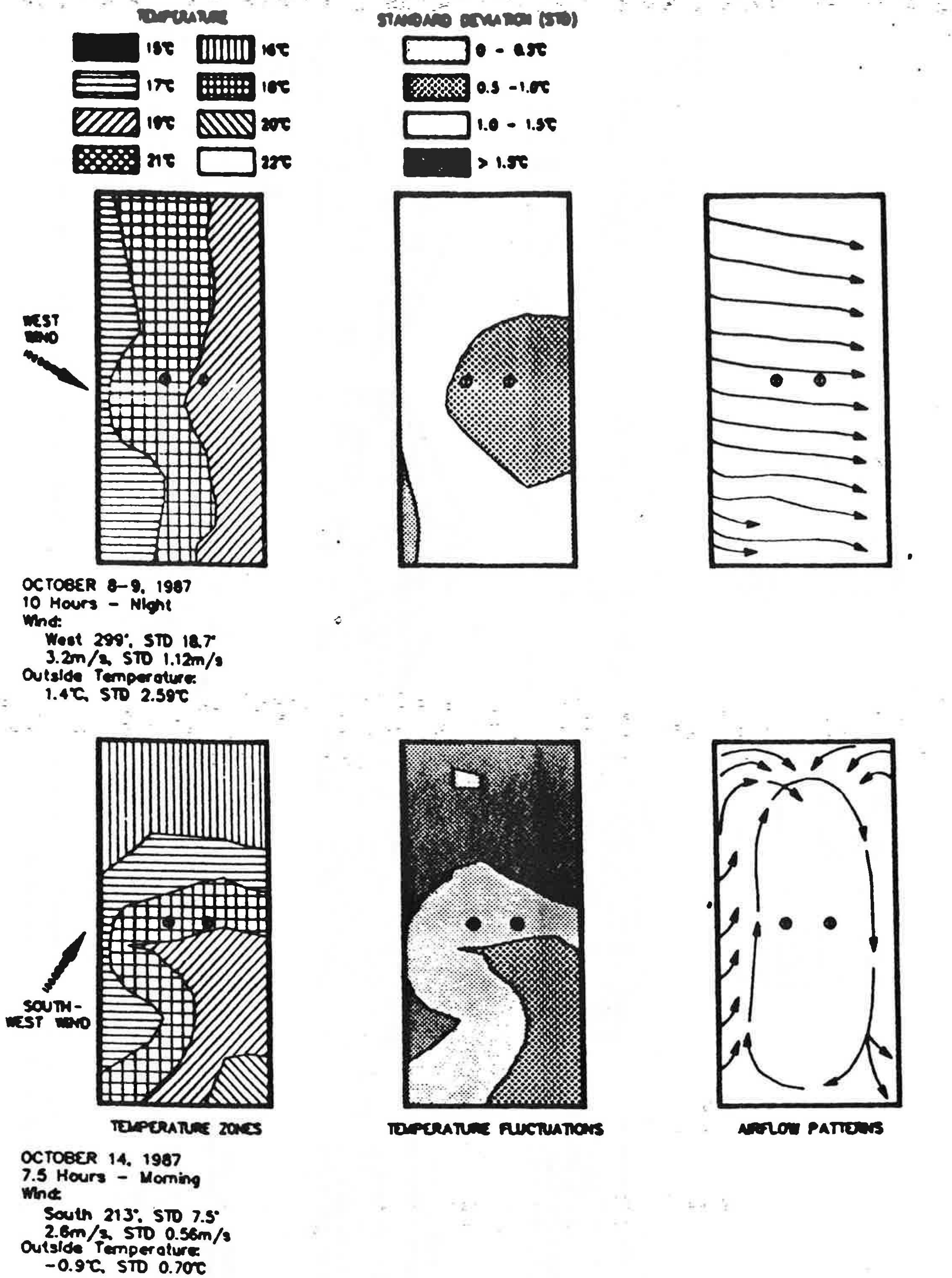


Figure 3: Plan View of temperature fluctuations and air flow patterns for a Naturally Ventilated Barn with thermostats 0.9 m above floor level

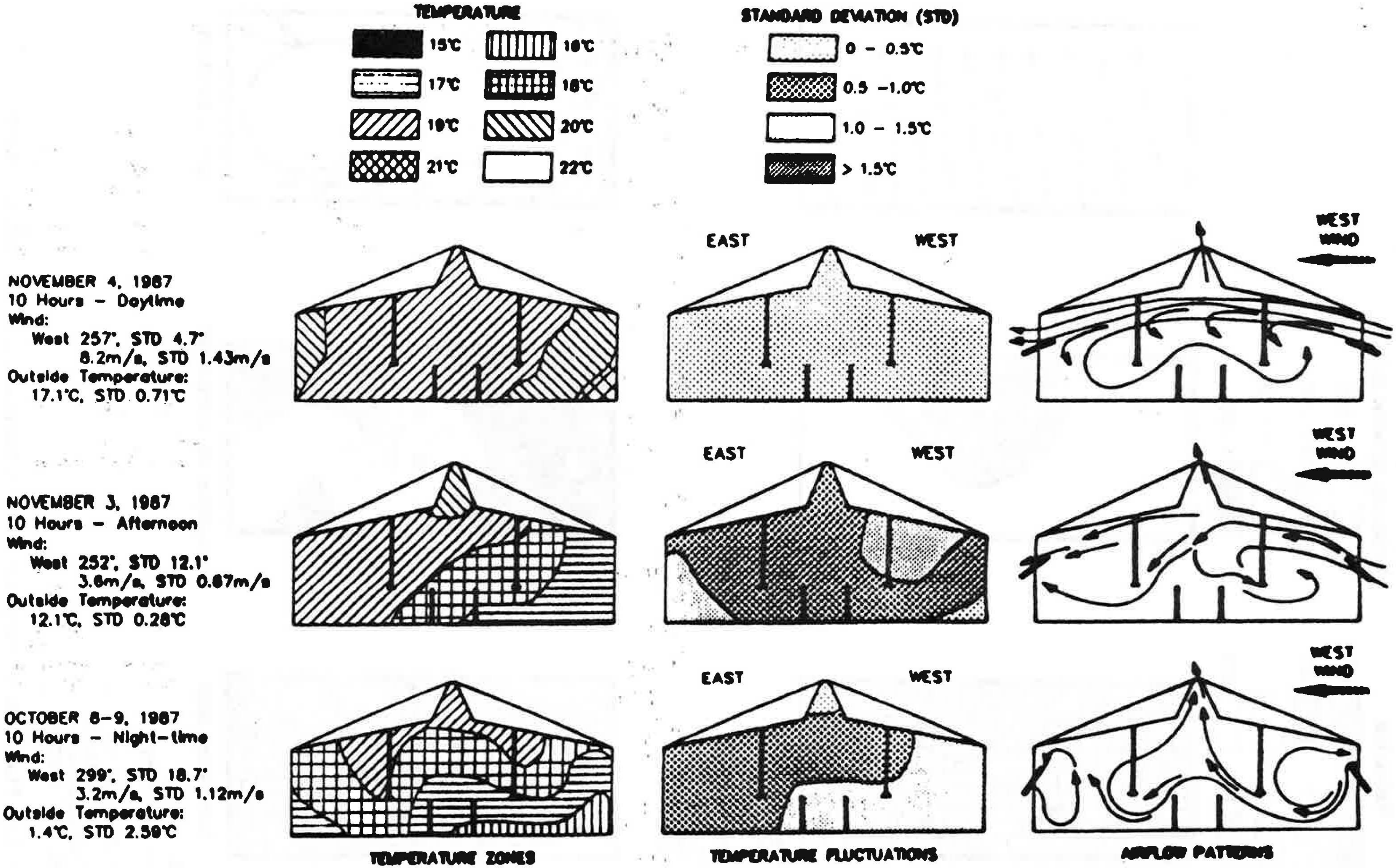


Figure 4: Temperature zones, temperature fluctuations and airflow patterns for a Naturally Ventilated Barn with a West Wind and thermostats 0.9 m above floor level.

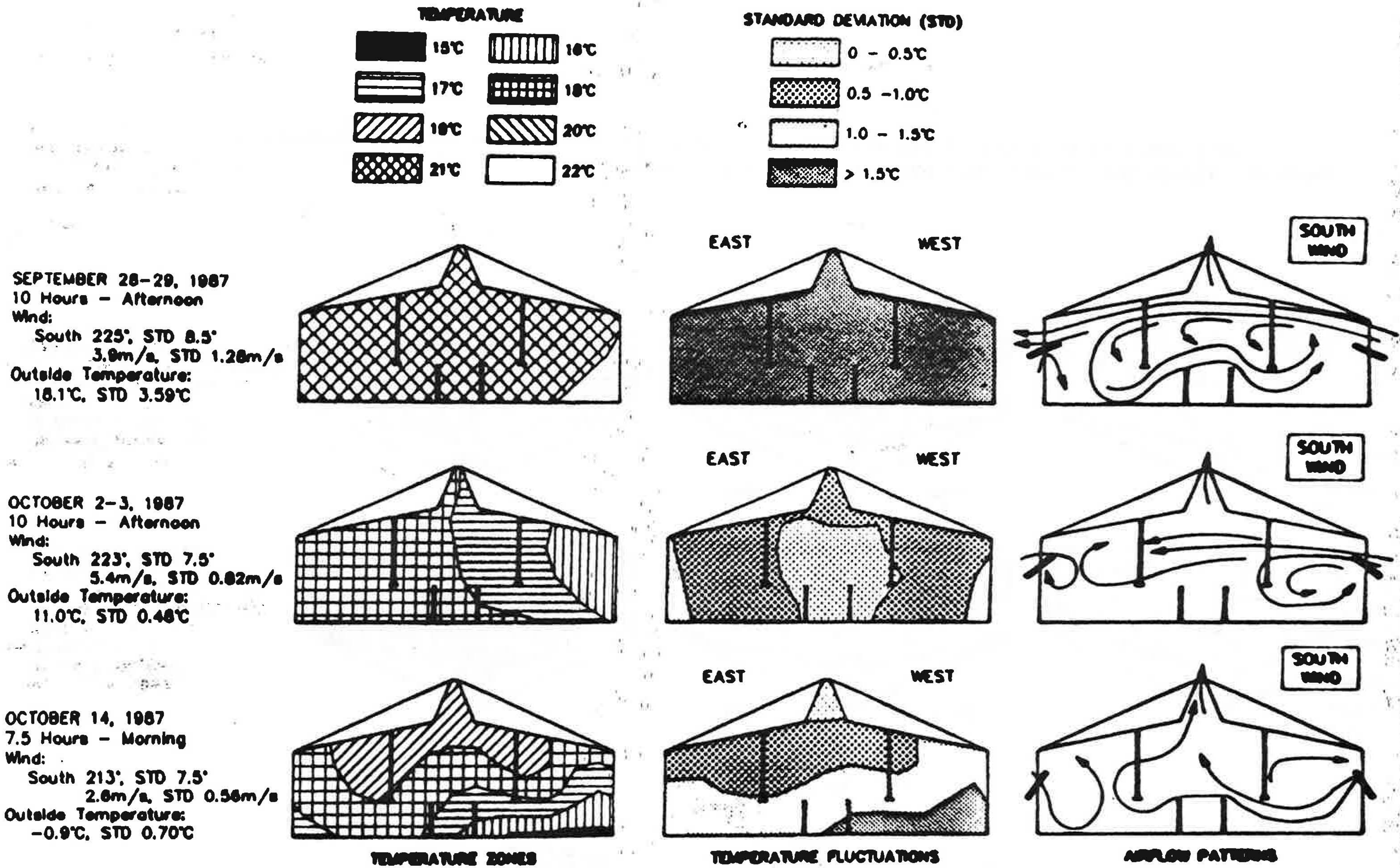


Figure 5: Central Cross-section profiles of temperature zones, temperature fluctuations and airflow patterns for a Naturally Ventilated Barn with a South Wind and thermostats at 0.9 m above floor level.

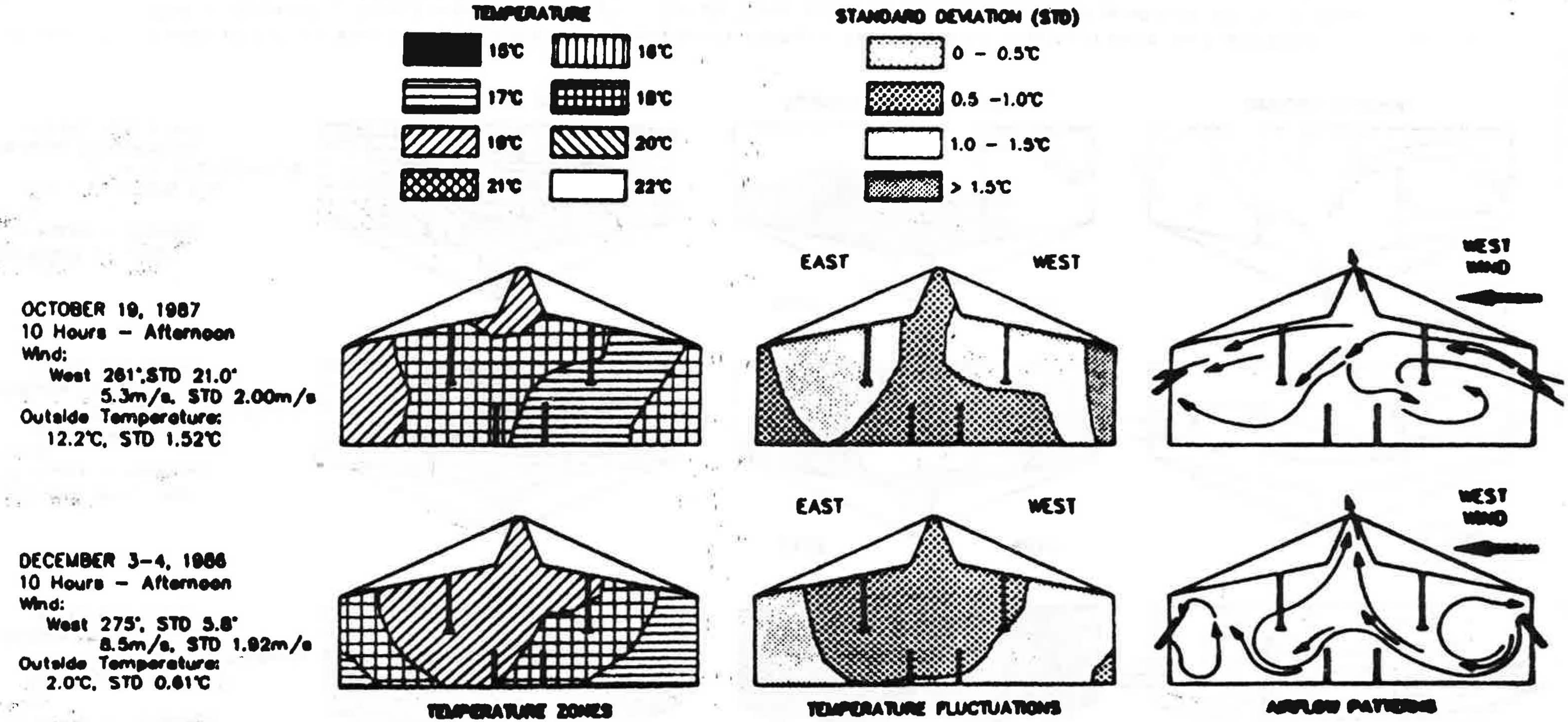


Figure 6: Central Cross-section profiles of temperature zones, temperature fluctuations and airflow patterns for a Naturally Ventilated barn with a West Wind and thermostats at 1.5 m above floor level.

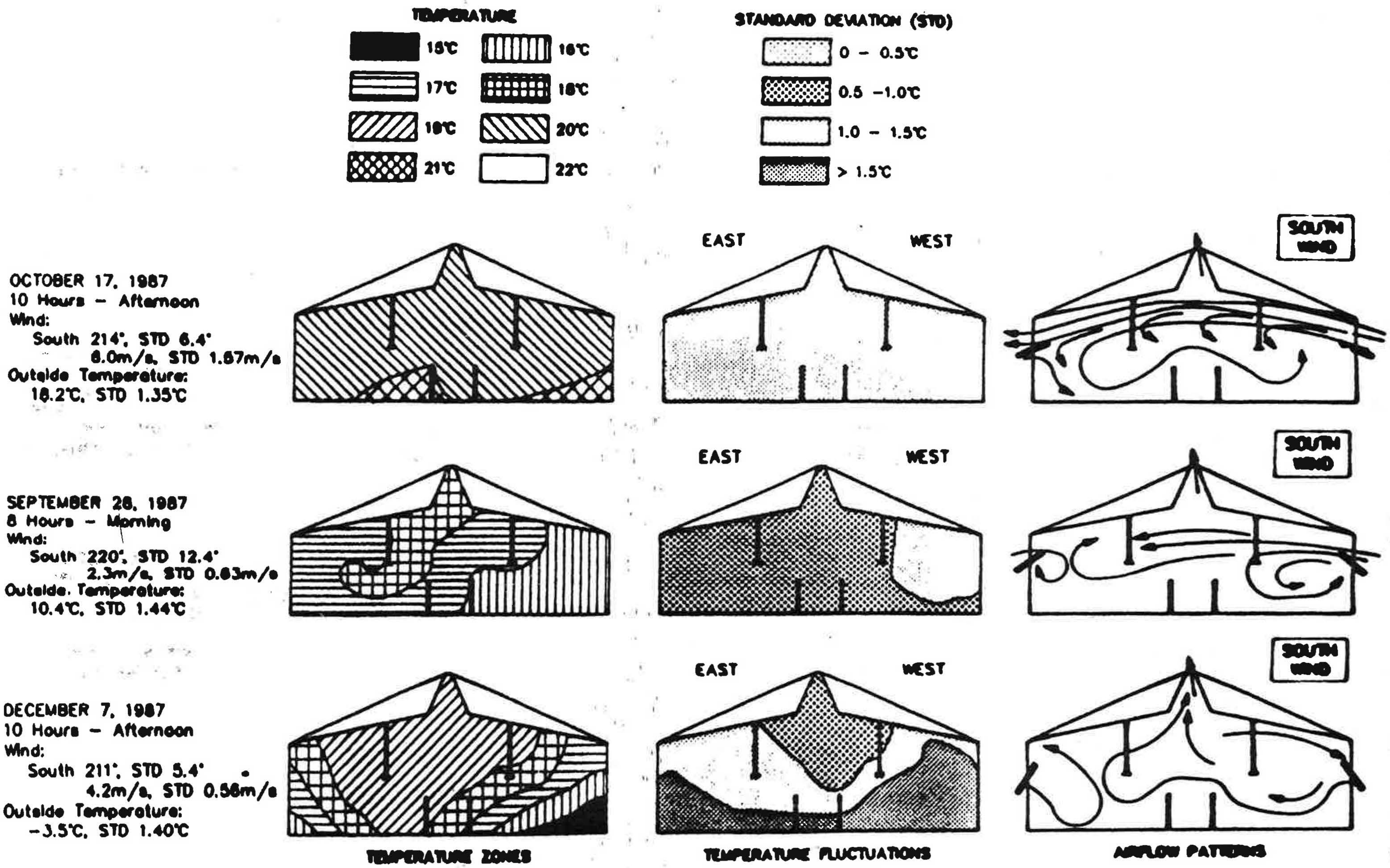


Figure 7: Central Cross-section profiles of temperature zones, temperature fluctuations and air flow patterns for a naturally ventilated barn with a South wind and thermostats 1.5 m above floor level.